PB83-161646

Gaseous Continuous Emission Monitoring Systems - Performance Specification Guidelines for SO2, NOx, CO2, O2, and TRS

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Dec 82

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-450/3-82-026		PB83 161646

4. TITLE AND SUBTITLE	5. REPORT DATE
Gaseous Continuous Emission Monitoring Systems Performance Specification Guidelines - SO_2, NO_x, CO_2, O_2, and TRS	December 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Emission Standards and Engineering Division	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Emission Measurement Branch (MD-19) Emission Standards and Engineering Division U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
DAA for Air Quality Planning and Standards (MD-10) Office of Air, Noise, and Radiation U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711	14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This document serves as a guideline for vendors, purchasers, and operators of gaseous continuous emission monitoring systems and offers suggestions for equipment performance and specifications, test procedures, and data reduction procedures for evaluating the capabilities of these systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
		13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release Unlimited	Unclassified	32
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

PB83-161646

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-82-026
October 1982

Air

EPA

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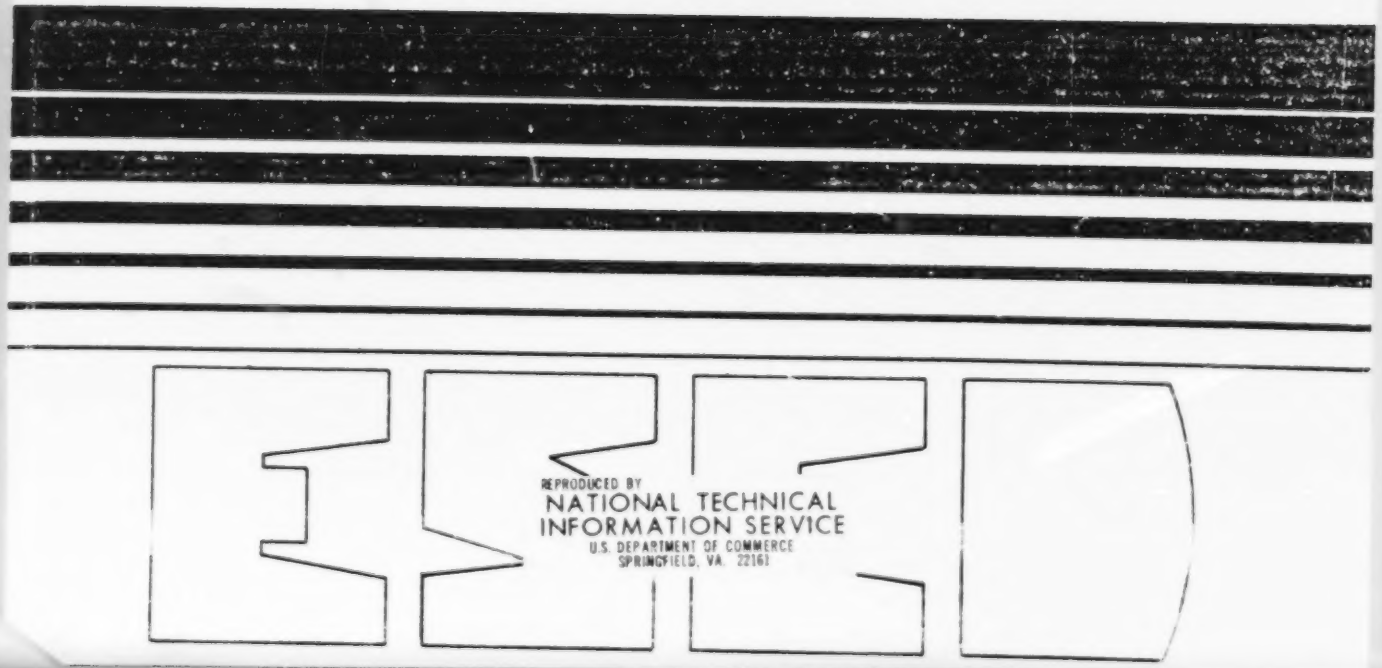

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Emission Standards and Engineering Division

U.S ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

October 1982

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GASEOUS CONTINUOUS EMISSION MONITORING SYSTEMS

PERFORMANCE SPECIFICATION GUIDELINES

SO_2, NO_x, CO_2, O_2, and TRS

1. Introduction

The purpose of these guidelines is to provide vendors, purchasers, and operators of gaseous continuous emission monitoring systems (CEMS's) with (a) guidelines for performance and equipment specifications and (b) suggested test procedures and data reduction procedures for evaluating the capabilities of gaseous CEMS's.

These guidelines are intended to supplement the requirements in the CEMS performance specifications (40 CFR Part 60, Appendix B) and not to be a prerequisite for acceptability of a CEMS for compliance with any regulation. Some of the suggested test procedures are not applicable to some specific types of CEMS's, in particular, single-pass, in situ CEMS's. The manufacturers of CEMS's should provide guidance, applicable procedures, and specifications for their type of equipment whether or not that equipment is specifically addressed in these guidelines.

These guidelines are intended for the evaluation of the initial capabilities of a CEMS. They also provide the user or operator with guidance that would aid in increasing knowledge of the operation of the CEMS and provide greater assurance that the CEMS will operate initially as it is intended.

These guidelines are not designed for the evaluation of CEMS performance over extended periods of time. The owner or operator may want to consider longer term evaluation of the CEMS to ensure satisfactory reliability. Separate quality assurance

procedures are required for this purpose. Such procedures may be similar to the procedures in the guidelines [e.g., the relative accuracy (RA) tests], but long-term evaluation procedures must include factors not part of this document. For example, complete quality assurance procedures should include CEMS data quality (e.g., frequent RA and calibration checks), assessment procedures, record keeping requirements, required maintenance schedules, limits of acceptability, and adjustment procedures. The user or operator should develop these procedures and specifications as appropriate for the CEMS and in compliance with the applicable regulations.

2. Definitions

Terms and expressions used throughout these guidelines are defined below:

2.1 Continuous Emission Monitoring System. The total equipment required for the determination of a gas concentration or a gas emission rate. The system consists of the following major subsystems:

2.1.1 Sample Interface. That portion of a system used for one or more of the following: sample acquisition, sample transportation, sample conditioning, or protection of the monitor from the effects of the stack effluent.

2.1.2 Pollutant Analyzer. That portion of the system that senses the pollutant gas and generates an output proportional to the gas concentration.

2.1.3 Diluent Analyzer. That portion of the system that senses the diluent gas (e.g., O_2 or CO_2) and generates an output proportional to the gas concentration.

2.1.4 Data Recorder. That portion of the monitoring system that provides a permanent record of the analyzer output. The data recorder may include automatic data reduction capabilities.

2.2 Types of Monitors.

2.2.1 Extractive Monitor. One that withdraws a gas sample from the stack and transports the sample to the analyzer.

2.2.2 In-situ Monitor. One that senses the gas concentration in the stack environment and does not extract a sample for analysis.

2.3 Span Value. The upper limit of a gas concentration measurement range that is specified for affected source categories in the applicable subpart of the regulations.

2.4 Calibration Gases. A known concentration of a gas in an appropriate diluent gas.

2.5 Calibration Gas Cells or Filters. A device that, when inserted between the transmitter and detector of the analyzer, produces the desired output level on the data recorder.

2.6 Zero Drift. The difference between the CEMS response to a zero-level calibration gas and the reference value after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place.

2.7 Calibration Drift. The difference between the CEMS response to a span-level calibration gas and its reference value after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place.

2.8 Response Time. The amount of time required for the CEMS to display on the data recorder 95 percent of a step change in pollutant concentration.

3. Performance and Equipment Specifications

Tables 1, 2, and 3 list guideline specifications for SO_2, NO_x, CO_2, O_2, and TRS (total reduced sulfur) CEMS performance and equipment parameters. Section 4 provides explanation and description of the parameters and the test procedures for determining these values.

The CEMS output range is defined in terms of the span value that is given in the applicable subpart of the regulations. This span value is generally 1.5 to 2.5 times the expected emission measurement so that the majority of the output data are produced in the mid-range area.

If no span value is provided, use the same criteria of 1.5 to 2.5 times the emission level in determining the CEMS range. For example, a coal-fired boiler fires 2.5 percent sulfur coal and employs a flue gas desulfurization scrubber for SO_2 removal. The SO_2 concentration at the inlet to the scrubber would average about 1500 ppm, the oxygen (O_2) concentration about 7.0 percent, and the carbon dioxide (CO_2) concentration about 12.0 percent. The appropriate span values for this location would be 3000 ppm for SO_2, 15.0 percent for O_2 (air at 20.9 percent O_2 is often used, but depending on the analyzer, this is not always the best value), and 20 to 25 percent for CO_2.

The scrubber designed for 90 percent SO_2 removal would produce SO_2 concentrations of about 150 ppm in the exhaust. The oxygen and carbon dioxide concentrations would remain constant through the scrubber provided no in-leakage of air occurs. The appropriate span

TABLE 1. SO_2 AND NO_x CEMS GUIDELINE PERFORMANCE SPECIFICATIONS

Parameter	Specifications
1. Response time	≤15 minutes
2. Zero drift, 2-hour	≤2.5 percent of span value
3. Zero drift, 24-hour	≤2.5 percent of span value
4. Calibration drift, 2-hour	≤2.5 percent of span value
5. Calibration drift, 24-hour	≤2.5 percent of span value
6. Calibration error	≤5 percent of span value
7. Relative accuracy[a]	≤20 percent or 10 percent of emission standard, whichever is less

[a] Expressed as the sum of the absolute mean of the difference plus the 2.5 percent error confidence coefficient of a series of tests divided by a reference value.

TABLE 2. O_2 AND CO_2 CEMS GUIDELINE PERFORMANCE SPECIFICATIONS

Parameter	Specifications
1. Response time	≤15 minutes
2. Zero drift, 2-hour	≤0.5 percent O_2 or CO_2
3. Zero drift, 24-hour	≤0.5 percent O_2 or CO_2
4. Calibration drift, 2-hour	≤0.5 percent O_2 or CO_2
5. Calibration drift, 24-hour	≤0.5 percent O_2 or CO_2
6. Calibration error	≤0.5 percent O_2 or CO_2
7. Accuracy[b]	≤1.0 percent O_2 or CO_2

[b] Expressed as the sum of the absolute mean of the differences plus the 2.5 percent error confidence coefficient of a series of tests.

TABLE 3. TRS CEMS GUIDELINE

PERFORMANCE SPECIFICATIONS

Parameter	Specifications
1. Response time	≤15 minutes
2. Zero drift, 2-hour	≤2 percent of span value
3. Zero drift, 24-hour	≤2 percent of span value
4. Calibration drift, 2-hour	≤5 percent of span value
5. Calibration drift, 24-hour	≤5 percent of span value for 6 of 7 test days
6. Calibration error	≤5 percent of span value
7. Relative accuracy[a]	≤20 percent or 10 percent of emission standard, whichever is greater

[a] Expressed as the sum of the absolute mean of the difference plus the 2.5 percent error confidence coefficient of a series of tests divided by a reference value.

value for SO_2 should allow for the measurement of some excursions from 90 percent control, so a factor of 2.5 is used. This results in a span value of about 375 ppm for SO_2.

Use these span values in determining the calibration gas values and the pollutant analyzer response ranges.

These calibration gases should be introduced to the CEMS so as to involve as much of the CEMS system as possible. For example, an extractive CEMS should be equipped to introduce calibration gases at the connection between the probe and the sample line near the stack or duct port location. It is not necessary to use this connection for daily drift checks, but the calibrations should be and response time checks must be made through the entire CEMS.

4. Performance Specifications Test Procedures

4.1 Location of Monitor. The proper location of the sample interface of the monitoring system is important for several reasons: (1) ease of access will facilitate proper maintenance, (2) CEMS measurement must be representative of the total emissions, and (3) proper location of the sample point(s) or path within the duct or stack is vital in meeting the RA requirements.

The CEMS should be located where it would most likely meet the RA requirements. It is suggested the measurement location be at least two equivalent diameters downstream from the nearest control device, the point of pollutant generation, or other point at which a change in the pollutant concentration or emission rate occurs and at least 0.5

equivalent diameter upstream from the effluent exhaust or control device. Individual subparts of the regulations may contain additional requirements. For example, for steam generating facilities, the location must be downstream of the air preheater.

Stack locations for CEMS's are generally farther downstream of control devices than most duct locations. Gas mixing is usually more complete meaning less stratification of pollutant concentrations and an easier task for determining RA. Disadvantages of stack locations include remoteness of the sample probe or the entire CEMS, as in the case of in-situ monitors. This remoteness often leads to poor maintenance and frequent breakdowns. For extractive CEMS's stack locations often mean long, heated sample lines from the probe to the analyzer. Long sample lines require more energy to maintain the heat and are subject to electrical failure more frequently than short lines.

Sample point(s) or paths within the stack or duct may be determined a number of ways. Performance Specifications 2 and 5 suggest that the location of the sample point(s) or the majority of the sample path for the CEMS be within the concentric inner 50 percent of the stack or duct cross section. Generally, any sample point(s) or path that include the centroid of the stack or duct and meets the other measurement location criteria above will provide samples representative of the average emission concentrations. Citation 7.7 provides further information in selecting measurement points for coal-fired sources.

The CEMS locations in duct work are usually the most accessible for maintenance and repair purposes, but often provide very difficult situations in terms of representative sampling. Because duct work is minimized for efficiency of space and cost, few duct locations provide a well-mixed condition desirable for CEMS installation. Frequently, by-passed gas is mixed with cleaned or scrubbed gas for reheating purposes, and the result is significant stratification of emissions within the duct work. Stratification can also occur due to poor scrubber operation, especially plugging of gas passageways and liquid-slurry spray nozzles. This latter type of stratification is most difficult to measure and is often temporally variable.

If stratification is suspected, the following procedure to locate a point or path of average emissions is suggested. For rectangular ducts, locate at least nine sample points in the cross section such that sample points are the centroids of similarly-shaped, equal area divisions of the cross section. Measure the pollutant concentration and, if applicable, the diluent concentration at each point using appropriate reference methods or appropriate instrument methods that give relative responses to pollutant concentrations. Then calculate the mean value for all sample points, and select a point, points, or path that provides a value equivalent to the mean. The sample location should be within the inner 50 percent area of the cross section.

For circular ducts, conduct a 12-point traverse (i.e., six points on each of the two perpendicular diameters) locating the sample points as described in 40 CFR 60, Appendix A, Method 1. Perform the measurements

and calculations as described above, and determine a point, points, or path that provides a value equivalent to the mean. The sample location should be within the inner 50 percent area of the cross section.

The performance specifications specify the location of the traverse points for reference method tests for RA. It is not necessary that the CEMS measurement location and the reference method traverse location be the same. For example, the CEMS may be located in the exhaust duct of a control device for accessibility purposes, but ports for reference method tests are not available or are inadequate in terms of the requirements in the performance specifications. In this case, the RA tests would be conducted farther downstream of the control device, probably in the stack, where ports are available and meet the requirements of the performance specifications. The results of the CEMS would be compared with the results of the reference method tests to determine RA.

4.2 Response Time. Determination of response time is important only when a short averaging time is specified in the applicable regulation or when time sharing makes quick response a necessity. The response time procedure provides a check of the effect of the sample interface on the calibration of the CEMS's. For this reason, it is necessary to check the entire sample transport line (if applicable), sample conditioning equipment (if applicable), the gas analyzer, and the data recorder. The procedure is as follows:

Introduce zero gas (or zero cell or filter into the CEMS). For extractive systems, introduce the specified calibration gas at the sample probe. If a gas analyzer is used to monitor more than one

source, perform the response time test for each sample interface. For in-situ systems, introduce the specified calibration gas at the sample interface (if applicable), or introduce a calibration gas cell or filter at an appropriate location in the gas analyzer. The appropriate location is one that includes all the components active in the measurement. This includes sample and reference measurement cells, electronics, lenses, and reflective surfaces. In some cases, substitute reflective devices are used to facilitate this use of calibration gases or cells.

When the CEMS output has stabilized, switch to monitor the stack effluent, and wait until a "stable value" is reached. A "stable value" is a CEMS response that shows a change of less than 1 percent of span value for 30 seconds. Record the upscale response time. Introduce a high-level concentration gas or cell to the CEMS and repeat the above steps recording the downscale response time. Repeat the entire procedure three times. Record the results of each test on a data sheet similar to that shown in Figure 1. Determine the mean values of the upscale and downscale response times. The slower or longer time is the CEMS response time.

4.3 Zero and Calibration Drift Measurements. The purpose of the drift checks is to determine the ability of the CEMS to maintain its calibration over a specified period of time. The performance specifications require a 24-hour drift determination and set the limit of acceptability for seven consecutive checks.

Date_____ High-level = _____ppm

Test Run	Upscale, min	Downscale, min
1		
2		
3		
Average	A =	B =

System Response Time (slower of A and B) = _____ min.

Figure 1. Response time.

Upon installation, the CEMS usually requires a break-in period during which the operating parameters can be adjusted to meet the conditions of the particular test site. The CEMS drift determinations during this break-in period often show excessive drift in the CEMS because of the frequent adjustments and the conditioning of the equipment. It is recommended that a CEMS conditioning period be undertaken prior to the performance specification test (PST) to allow for the initial adjustments and conditioning of the CEMS to be completed and provide greater assurance that the performance specifications will be met. This conditioning period should be 1 week or longer of CEMS operation.

Drift checks and calibrations (Section 5) with calibration gases or cells should be conducted so that all components active in the measurement of the gas concentration are included. For CEMS's using calibration gases, all sample conditioning equipment, including external filters and moisture traps, should be included in the measurement check. If calibration cells or filters are used, the cell or filter should be inserted in a measurement path that is the same as that used for stack gas measurement and that includes all the components of the measurement path, e.g., lenses, optical filters, mirrors, beam splitters, etc. The measurement signal should be a result of the same electronics involved in measuring the emission concentration. That should include special compensation components, such as for pressure and temperature.

In addition to the 24-hour drift check required by the performance specifications, 2-hour zero and span drift checks are suggested. The zero drift and calibration drift procedures are as follows:

4.3.1 Two-hour Drift. Introduce consecutively zero gas (or gas cell or filter) and high-level calibration gas (or gas cell or filter) at 2-hour intervals for a total of seven 2-hour periods. Determine and record the amount the CEMS output differs from the calibration reference value at the end of each 2-hour period (Example data sheet is shown in Figure 2). Conduct this test before making any zero or calibration adjustments to the CEMS during the test period. The 2-hour periods over which the measurements are conducted need not be consecutive, but must not overlap. Calculate the differences between the CEMS responses and the certified gas or cell value. The difference must not exceed the applicable levels listed in Tables 1, 2, and 3.

4.3.2 Twenty-four Hour Drift. At 24-hour intervals, introduce consecutively zero gas (or gas cell or filter) and high-level calibration gas (or gas cell or filter); make no adjustments to the CEMS during the test period. Record the amount that the CEMS output differs from the calibration reference value at the end of each 24-hour period (an example data sheet is shown in Figure 2).

No CEMS response for a calibration value should differ from the calibration reference value by more than 2.5 percent of span value for SO_2 and NO_x analyzers or 0.5 percent O_2 or CO_2 for diluent analyzers. For TRS monitors, at least six of the seven consecutive tests for a calibration value should not differ from the calibration reference value by more than 5 percent of span value.

4.4 Relative Accuracy Test. The relative accuracy test (RAT) is the primary check of the operation of the CEMS. The response of the

Test no.	Date	Time		Zero input		High-level input	
		begin	end	reading	difference	reading	difference
Arithmetic mean (Eq. 1)							
Drift (Eq. 4)							

Figure 2. Zero and calibration drift (2-hour and 24-hour).

CEMS to the stack gas emission levels is compared with reference method measurements that are representative of the total emissions from the source. To pass the RAT, the CEMS response must agree with the reference measurements to within 20 percent using the sum of the mean of the differences plus the confidence coefficient divided by the mean of the reference method values. Because of some variability inherent in the results of reference method tests and of CEMS responses, the confidence coefficient usually accounts for about half of the calculated RA value. Therefore, the limit of direct comparison between reference method results and CEMS responses is about $\pm$10 percent.

The respective performance specifications provide detailed information on the number of test points, the number of test runs, the sampling and analytical methods, and the calculation procedures required for the RAT. The most important factor in performing and passing the RAT is quality assurance -- both for the CEMS and the reference method tests. It is strongly suggested that audits be included in the testing program and that experienced, qualified personnel conduct the RAT's.

There are a few suggestions for conducting the RAT that may facilitate the testing and reporting. First, note that the location of the ports for the RAT need not be the same as for the CEMS, but must be such a location that is representative of the total process emissions. An exhaust stack location is most likely to meet this criterion. Should no stack location be available or should control equipment inlet testing be necessary, schemes for sampling multiple

ducts might be required. In such a case, there must be coordination between test crews for simultaneous testing.

Another suggestion that could facilitate the satisfactory completion of the RAT regards the allowance in the performance specifications that more than nine test runs may be collected with the option to reject up to three sets of test results, so long as at least nine test results are used to determine the RA. It is suggested that more than nine test runs (up to 12) be conducted for each CEMS RAT, so that this option is available should one or more of the test runs be contaminated or otherwise determined to be unacceptable following the test period. All measurement data must be reported in the PST report.

Orsat data collected in the field can be checked to determine whether the ratios of diluent concentration corresponds to the stoichiometric combustion products ratio for the fuel being used. Citation 7.8 details this procedure and acceptable limits for these comparisons.

5. Continuous Emission Monitoring System Calibration

In preparation of the CEMS for undergoing the PST's, proper calibration of the analyzers is one of the most important functions. Manufacturers have procedures specific for their instruments and usually supply a manual with a calibration curve or chart prepared for the analyzer by the manufacturer in the home laboratory. Many purchase agreements include a provision for an on-site calibration to be performed by the manufacturer upon installation and startup.

The two purposes of performing calibrations on a CEMS are: (1) to resolve whether the CEMS can accurately determine the concentration of

a known source, and (2) to determine whether the CEMS response over the range of measurements is predictable, e.g., linear. The wide range of instrument types and calibration procedures precludes including specific procedures for performing these calibrations in these guidelines. In general, a known concentration source (e.g., compressed gas, gas cell, or optical filter) is introduced to the analyzer, and the analyzer response is compared with the known value.

If a CEMS response curve is supposed to be linear, this may be checked by introducing a zero or low-level gas followed by a high-level gas (see Section 5.1) and preparing a linear calibration curve between the two responses. Then, a mid-level gas is introduced to the analyzer, and the analyzer response is compared to the calibration curve. The calibration curve should predict the known mid-level concentration to within $\pm$5 percent of span value (or 0.5 percent O_2 or CO_2 for diluent analyzers).

If a CEMS is designed so that the response curve is nonlinear, an alternative calibration error test must be used. The CEMS manufacturer may recommend a procedure for determining the response curve. At a minimum, three calibration points (low-level, mid-level, and high-level values), and a zero value should be used in establishing the calibration curve. Introduce the calibration gases and the zero gas one at a time, and record the responses. Prepare a calibration curve from the responses according to the manufacturer's recommendations. Introduce a fourth calibration gas with a known value between the mid-level and the high-level values, and record the response. The CEMS response for this gas as determined from the calibration curve should agree with the certified gas value to within $\pm$5 percent of span value.

The manufacturer's operating manual should provide at a minimum a three-point calibration check or a suitable alternative for determining the CEMS response to known concentrations. The recommended calibration levels and concentration verification procedures are as follows:

5.1 Calibration Levels. A minimum of three calibration concentration levels are recommended to perform the checks on the CEMS. These concentrations are defined below.

5.1.1 High-Level. A level that is equivalent to 80 to 90 percent of the span value.

5.1.2 Mid-Level. A level that is equivalent to 45 to 55 percent of the span value.

5.1.3 Zero Level. A level that is equivalent to less than 0.25 percent of the span value.

5.2 Gas Cylinder Analysis. There are several, equally acceptable alternatives for checking or obtaining known concentrations of calibration cylinder gases. The principle behind each procedure is to correlate the gas concentration in the cylinder with a known reference value. The reference value can be based on the measurement by a recognized materials and measurements authority, such as the National Bureau of Standards, or can be measured more directly with established reference procedures, usually wet chemical methods. The alternative procedures are described below:

5.2.1 Manufacturer-Certified Cylinder Gases. These are calibration gases prepared according to the protocol defined in Citation 7.9.

5.2.2 Tagged Cylinder Gases. Tagged cylinders are those supplied by the vendor with a label indicating the vendor's measurement of the gas concentration, but may not have been performed in the manner specified in the protocol. The concentration of these cylinder gases may be checked by performing reference method tests on the cylinder gases. Procedures for sampling and analyzing these calibration cylinder gases are described in Citations 7.1 and 7.10. Triplicate analyses are required for each calibration gas with each analysis in a set within 10 percent (or 15 ppm for SO_2 and NO_x, whichever is greater) of the average. If this criterion is not met, the measurements should be discarded and the analyses repeated. If the average of the triplicate reference method tests is within 5 percent of the vendor's tag value, use either the measurement average or the tag value as the correct concentration. If the triplicate average is not within 5 percent of the tag value, use a measured average for the cylinder concentration value. (An example data sheet is shown in Figure 3.)

5.3 Calibration Gas Cell or Filter. Cells or filters used to calibrate CEMS's are usually short-path cells of high concentration gases designed to simulate concentrations of a long-path, stack measurement.

Date _____

Cylinder Tag Value(s) _____ (SO_2, NO_x, TRS).

Reference Method Used _____

Analyzer _____

Sample run	Mid-level ppm	High-level ppm
1		
2		
3		
4		
5		
6		
Average		
Maximum % Deviation[b]		

[a] Not necessary if the protocol in Citation 7.9 is used to prepare the cylinder.

[b] Must be $\leq \pm$ 10 percent of the average of all runs.

Figure 3. Analysis of calibration gases[a].

Determining the pollutant concentration in the gas cell is difficult and would serve little purpose in the calibration of the cell. More directly, what must be demonstrated is that the cell produces a known analyzer response and that the response is within the range desired.

This can be accomplished by comparing the analyzer response produced by the calibration cell with a known stack concentration. The known stack concentration can be produced in a laboratory source simulator using certified calibration gases as described in Section 5.1 or by direct reference method measurements. The effects of temperature, and to some extent, pressure, can be quantified as well, with this type of calibration check.

Another approach is to compare the CEMS response to calibration cells after the CEMS is installed on the stack and its accuracy has been verified with the reference method test measurement of the stack gases. This approach automatically accounts for stack gas interferences and temperature conditions, but does not provide certified calibration values for pretest calibrations.

6. Equations

6.1 Arithmetic Mean. Calculate the mean of the differences of a data set as follows:

$$\bar{d} = \frac{1}{n} \sum_{i=1}^{n} d_i \qquad \text{(Eq. 1)}$$

Where:

d = Difference between the measured value and a reference value.

n = Number of data points.

$\Sigma\, d_i$ = Algebraic sum of the individual differences, d_i.

6.2 Standard Deviation. Calculate the standard deviation, S_d, as follows:

$$S_d = \left[\frac{\sum_{i=1}^{n} d_i^2 - \frac{1}{n} \left(\Sigma\, d_i \right)^2}{n-1} \right]^{1/2} \qquad \text{(Eq. 2)}$$

6.3 Confidence Coefficient. Calculate the 2.5 percent error confidence coefficient (one-sided), CC, as follows:

$$CC = t_{.975} \frac{S_d}{\sqrt{n}} \qquad \text{(Eq. 3)}$$

Where:

$t_{.975}$ = t-values (see Table 4).

Table 4. t-Values

n^a	$t_{.975}$	n^a	$t_{.975}$	n^a	$t_{.975}$
2	12.706	7	2.447	12	2.201
3	4.303	8	2.365	13	2.179
4	3.182	9	2.306	14	2.160
5	2.778	10	2.262	15	2.145
6	2.571	11	2.228	16	2.131

[a] The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of individual values.

6.4 Relative Accuracy. The RA is a measure of the difference between the mean value or expected value and the desired value. Calculate the RA as follows:

$$RA = \frac{|\bar{d}| + |CC|}{RV} \times 100 \qquad \text{(Eq. 4)}$$

Where:

RV = Reference value, as defined in Sections 4.3.1, 4.3.2, and 4.4.

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